Use of Three-Dimensional Spiral Computed Tomography Imaging for Staging and Surgical Planning of Head and Neck Cancer

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We compare four different three-dimensional (3D) reconstruction methods of spiral computed tomography (CT) data for head and neck cancer to establish the method best suited for specific uses, eg, staging of lymph nodes and viewing of spatial relationships between the tumor, fascial spaces, adjacent soft tissues, and others structures. We evaluated a series of 10 patients (six men and four women), aged 32 to 60 years. Of these, five were histologically diagnosed with squamous cell carcinoma, two with lymphoma, one with thyroid cancer, one with Kikuchi's disease or necrotizing lymphadenitis, and one with esthesioneuroblastoma. All scans were obtained using high-resolution spiral CT (General Electric Medical Systems, Milwaukee, WI). The collimations used were 3 mm and 5 mm, matrix 512 × 512, and reconstruction interval not more than 3 mm. Scanning was performed from the skull base to the aortic arch. Iodinated contrast medium was injected so that the blood vessels were clearly differentiated from nodes. Different techniques of three-dimensional reconstruction were employed, including shaded surface display (SSD), multiplanar reconstructions (MPR), maximum intensity projection (MIP), 3D volume rendering (VR), and combined techniques. The reconstructions were performed in a variety of planes, including sagittal, coronal, and oblique views. In our series of selected patients, the technique of 3D VR showed potential advantages over other techniques. The MIP technique was useful in analyzing the patency of vessels and to exclude thrombus, compression, or displacement by tumor. The use of combined techniques such as SSD and MPR, accurately demonstrated the levels of lymph nodes and the relationship between the tumor projection of interest and various anatomic structures. In conclusion, 3D reconstruction of CT data is useful in the localization and staging of neck tumors and assists in surgical planning and radiation treatment.

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THE TASK of the radiologist, when studying cervical lymphadenopathy, is threefold. In the first place, it is to evaluate the size, extent, and staging of the tumor. Second, it is to identify enlarged lymph nodes, classify by levels, characterize their behavior, in terms of density, contours, size, presence of necrosis and calcification. Third, the radiologist should provide the surgeons and oncologists an idea of anatomic approach, in a three-dimensional (3D) view, for surgery, biopsy, or radiation therapy.

Squamous cell carcinoma accounts for more than 90% of head and neck aerodigestive tract malignancies.[1] The evaluation of the status of the cervical metastatic nodes is one of the most important means of evaluating the prognosis for patients with these malignancies, in which the presence of even a single positive node decreases survival by as much as 50%.[2] The crucial element in the initial evaluation of the patient with squamous cell carcinoma of the head and neck has been the physical examination; however, the clinical assessment of the status of the cervical lymph node is inaccurate by physical examination alone. As reviewed by Nason et al, in a series of more than 200 patients, the frequency of false-negative clinical diagnosis was 29%.[3] In another series, Synderman et al reported 20% of the patients with clinically identifiable adenopathy had lymph node metastatic disease at histologic evaluation of neck dissection specimens. The advent of modern imaging technique has modified this situation. For the majority of investigations, computed tomography (CT) has been the imaging modality of choice for staging and surgical planning of head and neck cancer.[4] This is due in part to the superior quality of the images obtained on CT, and in part to the reduced cost and time in acquiring the images, as well as the increased availability of CT compared with magnetic resonance imaging (MRI) for many clinical applications.[5] Furthermore, CT can be performed on claustrophobic, obese, heavily monitored patients,

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or when other contraindications for MRI exist, such as pacemakers, diamagnetic materials, cochlear implants, etc. In addition, CT is faster and is less expensive compared with MRI. The development of spiral CT machines has emphasized these advantages even more. With spiral CT there are no interscan delays, so that in an equal amount of time a spiral scanner can acquire the same volume of CT data faster than a conventional CT scanner.[6] The volume of information acquired may be sliced with a wide variety of spacing intervals available, and the sections can therefore be applied to optimally depict pathologic processes. Optimal scan acquisition is dependent on a high heat capacity of the x-ray tube, efficient detectors, the slipping gantry, and the reconstruction algorithm.[6]

CT 3D reconstruction images have been largely used to provide target volumes for radiation therapy, thus increasing the importance of accurate anatomic delineation. The main aim in radiation therapy planning is irradiating a chosen field to the desired dose, while sparing the adjacent normal tissue, since irradiation of normal tissue can lead to complications, which may decrease patient survival. It has been estimated that improved targeting could increase cure rates by 3% to 4%, an increased annual salvage of 10,000 lives among the nearly 300,000 cancer patients who undergo treatment each year.[7] Such targeting accuracy requires a high degree of conformity between the high-dose region and the target volume. Since both the target and the cross-firing beams describe highly complex 3D volumes, accurate 3D imaging and reconstruction techniques offer obvious advantages over two-dimensional ones.[8]

As previously described by Kalender and Polacin,[9] the acquisition of volumetric data in spiral CT is achieved by moving the patient at a constant rate through the gantry, while simultaneously rotating the source-detector assembly. The x-ray traces a helix on the patient's surface, resulting in a helix of raw projection data from which planar images are generated. Unlike conventional CT, the interval between reconstructed transaxial images can be chosen retrospectively and arbitrarily.[10] The introduction of slip-ring technology[11] into the gantry has allowed continuous rotation of the x-ray source, thus decreasing the interscan delays. One benefit of this technique is that the volumetric data set of a spiral CT is acquired during a single breath hold, eliminating respiration artifact. Another advantage is the ability to reconstruct overlapping images, reducing the partial volume averaging, which increases the possibility of detecting small lesions.[6,8] Because the data of a spiral scan are acquired over a short period of time, the enhancement effect of intravenous contrast material significantly improves the resolution of the image. This finding determines one of the most important uses of spiral CT, which is its application for vascular imaging.[13] The high-speed acquisition allows imaging of the arterial phase of a properly timed bolus of intravenous contrast material in a large volume of patient anatomy. The inherent contrast available with CT, associated with the ability to create images without the superposition of overlying structures, is a determining factor in performing CT angiography (CTA), allowing reliable visualization of stenoses, focal or diffuse aneurysms, thromboses, calcifications, atheromatous plaques, and vascular malformations.

The aim of this study was to establish whether CT 3D reconstructions are useful for diagnosis and staging of head and neck cancer and metastatic lymph nodes, using multiplanar reformation (MPR), shaded surface display (SDD), maximum intensity projection (MIP), 3D volume rendering (VR), and combined techniques. We compared different reconstruction techniques and attempted to determine which technique was best suited to different cases of head and neck malignancy diagnosis and staging.

MATERIAL AND METHODS

Between December 1998 and March 1999, a series of 10 patients (six men and four women), aged 32 to 60 years, were enrolled in this study. Of these, five were histologically diagnosed with squamous cell carcinoma, two with lymphoma, one with thyroid cancer, one with Kikuchi's disease or necrotizing lymphadenitis, and one with esthesioneuroblastoma. Nine patients were referred from the Head and Neck Surgery Department and one from the Department of Neurosurgery. None of the patients had contraindications to intravenous injection of iodinated contrast material. All patients underwent a spiral CT scan on a 9800 HiSpeed Advantage Scanner (General Electric Medical Systems, Milwaukee, WI) with 3-mm and 5-mm collimation, and a pitch of 1.

Patients were placed in the supine position. Scanning was performed from the skull base to the aortic arch. Intravenous enhancement was achieved using 140 mL of nonionic contrast material (Omnipaque 300; Nycomed, Princeton, NJ), which was intravenously infused at a rate of 3 mL/s, using a power injector and a 20-gauge intravenous catheter inserted into the antecubital vein with a 20-second scan delay. The CT data set was downloaded via a network to an Advantage Windows workstation (version 3.1, General Electric Medical Systems). The studies were reviewed by two radiologists (R.G.R. and V.S.) and a variety of different imaging methods were employed and compared with each other and with the initial axial images CT slices.

Currently, a variety of 3D techniques are available for displaying spiral CT images. The different imaging techniques can be divided into two basic classes, which are surface-rendering or volume-rendering methods. The main difference between the two categories is that surface rendering methods entail explicit delineation of surfaces, whereas in volume rendering, no such delineation is performed, which is a potential advantage of volume rendering. However, both methods make use of surface shading to produce their display.[12] In the current work, we compared the following four methods of 3D imaging: MPR, MIP, SSD, and VR.

Multiplanar Reconstruction

MPR is the simplest way of processing helical CT data, and is, in fact, not really a 3D technique. In order to generate MPR images the CT data are first interpolated, producing a data set with cubic voxels. The interpolated data are then resliced, following a contour defined by the user. The contour can be a simple planar cut, or a curved surface, which follows the shape of an organ. The ability to "scroll" back and forth through the data in a given plane gives the illusion of a 3D display. MPR is available with most CT consoles, and conserves all of the information present in the data, being only an interpolation and replacing, not processing, technique (Fig 1).

Shaded Surface Display

The first step in generating a SSD display is selecting a threshold value that includes the majority of the voxels of interest. This step is usually performed manually, since signal intensities, even of the same organ, may vary between scans. All voxels with values above the threshold are set to a value of 1; all voxels below the threshold are set to a value of 0. In effect, the collected data are transformed into binary data. A surface encompassing all voxels of interest is then generated. Depth perception is created by projecting a light source from a given orientation, and shading the image according to light reflection properties, for example, the intensity of light reflected from a point of the surface and reaching the viewer decreases with the distance of that point from the viewing plane. The reflected light is also a function of the cosine of the angle between the direction of the light rays and the normal to the surface at the point under consideration. There are additional optical properties one can use to improve the shading, such as assigning a color to the reflected light, or a transparency to the tissue, leading to a fraction of the light being transmitted through. This shading of the surface gives a 3D appearance to the rendered image[11] (Fig 2).

The major drawback of SSD is the loss of information in the data set. Once the thresholding is carried out and the data are transformed into binary data, the attenuation information is, in effect, lost. However, in situations where this information is not necessary, and only a surface display is required, this method has computational advantages. In addition, like MIP, SSD is commonly available as part of the CT package. SSD can be combined with other rendering methods, such as MPR, to give more detailed views of the anatomy (Fig 3).

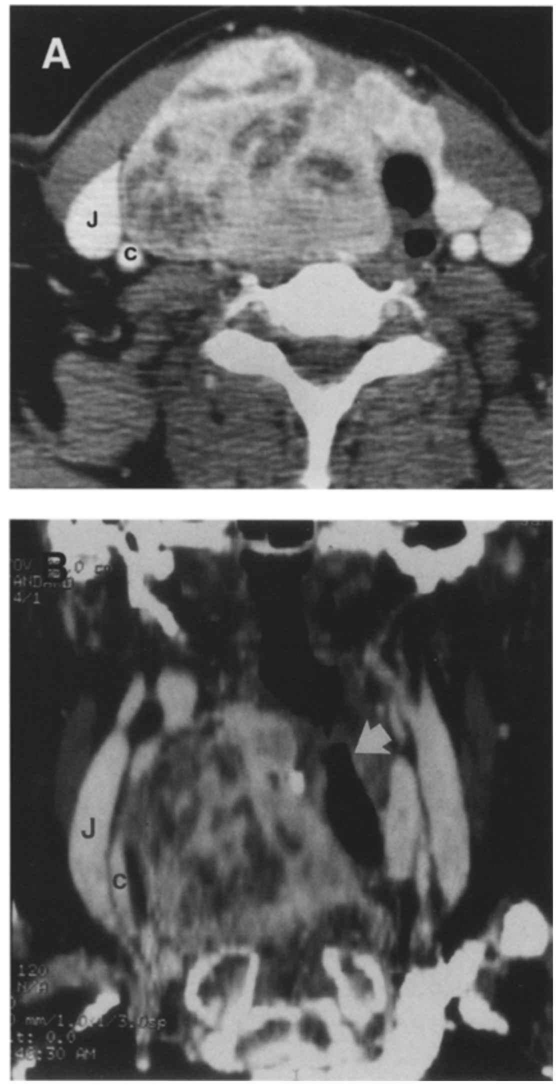


Fig 1. Thyroid cancer in a 68-year-old woman. (A) Contrast-enhanced CT scan of the neck, axial view, shows a large inhomogeneously mass in the right lobe of the thyroid. There is lateral displacement of the internal jugular vein (J) and carotid artery (c). (B) MPR coronal image shows lateral displacement of the right carotid artery (c) and internal jugular vein (J), and displacement of the airway to the left (arrow).

Maximum Intensity Projection

MIP is a 3D visualization technique that is used primarily in the display of CT angiography data sets. It is an excellent technique for evaluation of vessels, due to its ability to provide reliable separation of the enhanced stenotic lumen from calcified plaque. Blood vessel attenuation is maximized by injection of contrast material. To optimize target vascular enhancement, the timing of contrast media bolus should be related to the hemodynamic condition of the patient, such as blood pressure and heart rate. The method is as follows: parallel rays are cast through a volume of interest (VOI) from a given viewing direction. The maximum value of CT number that each ray

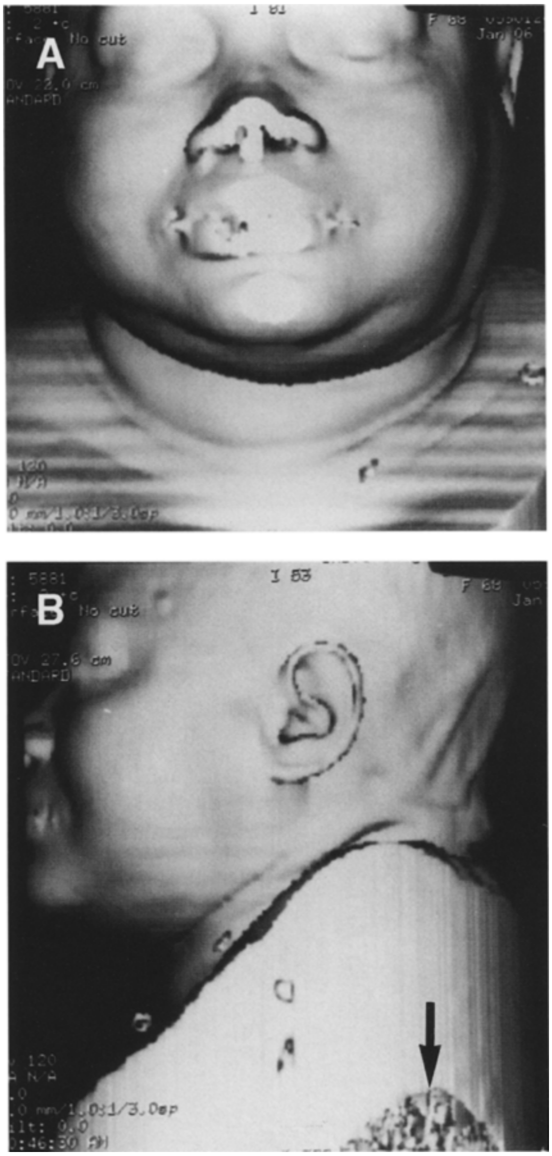


Fig 2. Shaded surface display (SSD). (A) Anteroposterior and (B) lateral views reveal the surface anatomy; the internal structures are not seen. The lateral margin of the image reveals only artifact, rather than internal anatomic structures (arrow).

encounters along its path is then displayed. For CTA, one must use editing techniques to exclude structures that might occlude the vessels. Bones, for example, have a high CT number and will therefore be prominent in MIP images, and thus it is usually necessary to exclude them from the region of interest if one wishes to view only the vessels.[12]

The advantages of the MIP technique are that the images are not threshold-dependent, and they preserve the full data of the CT images, in terms of attenuation information. Thus, important information about vessel calcification is not lost (Fig 4). In addition, the more experienced user allows greater information to be included if a more detailed segmentation processes is employed, excluding all unwanted pixels values above those of targeted structures. However, MIP does not contain depth information, so one does not obtain a 3D view of the structures. This is because the voxel with the highest CT number is displayed, regardless of its position along the ray's path. Thus, MIP images are most efficiently used to display situations where anatomic structures are not superimposed on each other. This drawback can be overcome if one uses a cine display to view the MIP from varying viewing angles. Another advantage is that

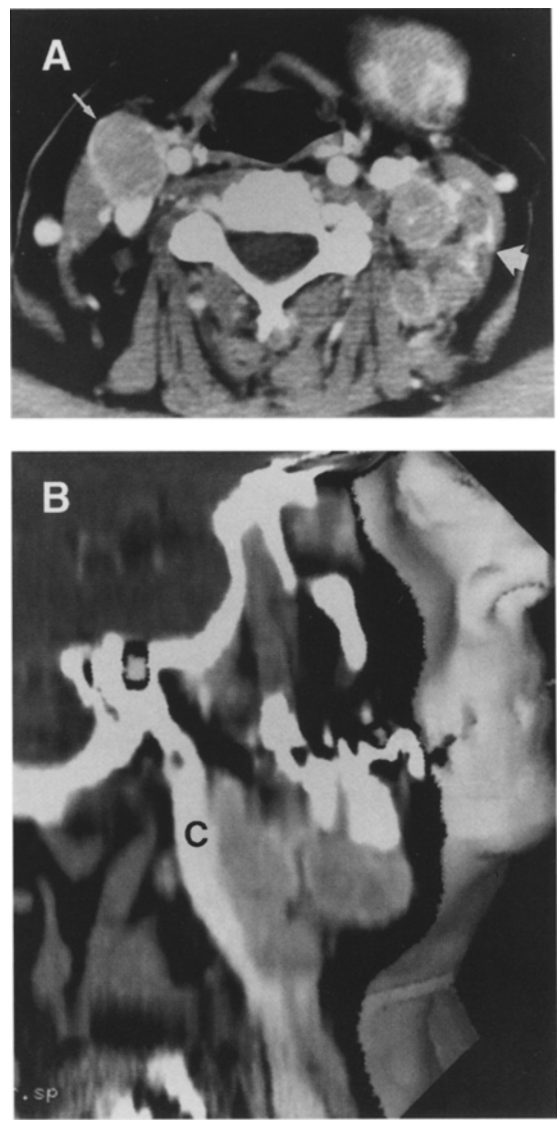
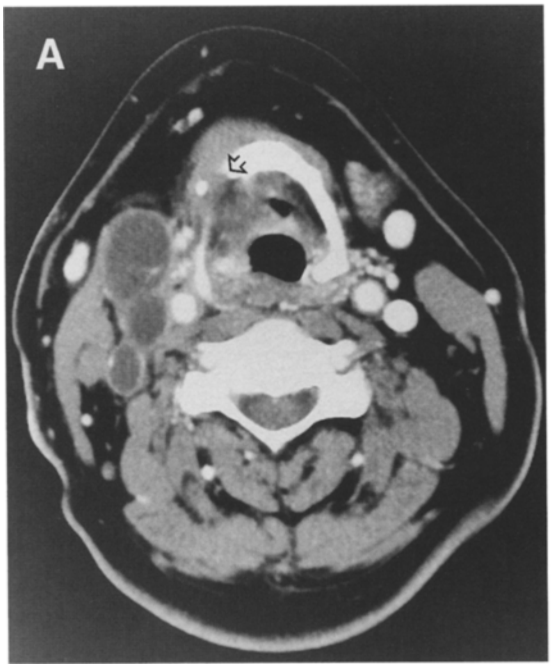
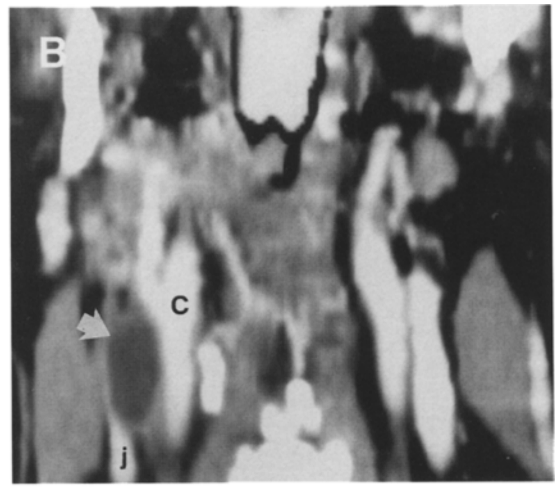


Fig 3. Esthesioneuroblastoma in a 78-year-old woman. (A) Contrast-enhanced CT scan of the neck, axial view, shows several large metastatic lymph nodes involving the internal jugular chain, bilaterally (small arrow), and the left spinal accessory chain (large arrow). (B) Combined technique, MPR + SDD, sagittal-oblique view, reveals the relationship between the internal carotid artery (c) and the lymph nodes anterior to the carotid artery.





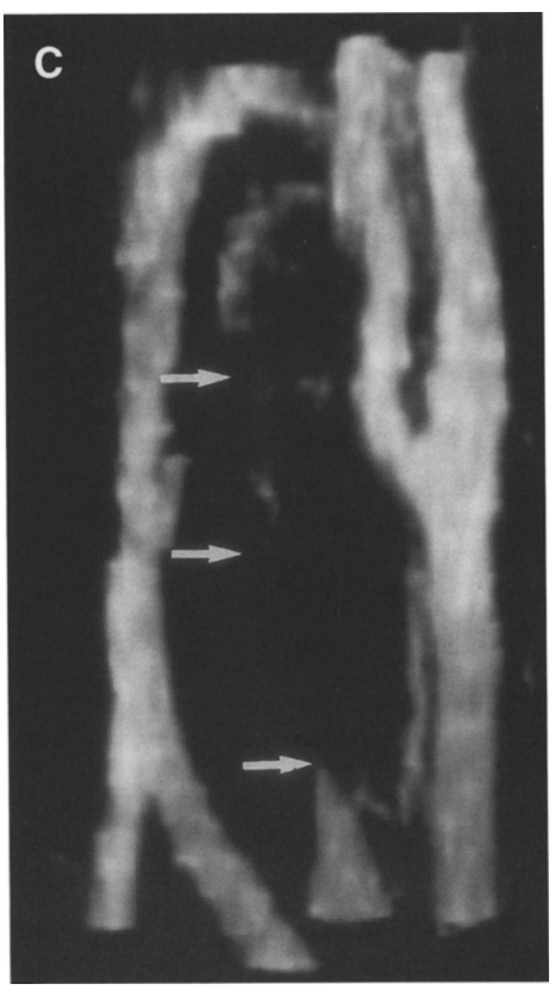


Fig 4. Supraglottic squamous cell carcinoma in a 47-year-old man. (A) Contrast-enhanced CT scan, axial view shows a tumor in the right piriform sinus with erosion of the hyoid bone (arrow). There are multiple necrotic lymph nodes in the right internal jugular and spinal accessory chains. (B) Combined techniques, MPR + SDD, coronal view, reveals thrombosis of the right internal jugular vein (arrow). The patent jugular vein (j) is visible above and below the thrombus. The carotid artery (c) is medial to the thrombus. (C) Maximum intensity projection (MIP), coronal view, shows the extent of the right internal jugular thrombosis (arrows). The carotid artery is medial to the thrombus.

MIP imaging is commonly available with commercial software packages, and is included as part of commercial CT packages, such as the one used in the present work.

Volume Rendering

VR is a method originally proposed by Drebin et al.[14] Unlike SSD and MIP, VR makes use of the full volumetric data directly, to produce 3D views. Thus, VR techniques preserve the full information contained within the data set (Fig 5). The VR technique involves direct imaging of the CT data, based on the classification of the data voxels into several tissue types (eg, bone, fat, tissue, and air), each of which has a characteristic range of Hounsfield numbers. In the current work, we used Rendo_avs, a VR tool developed at The University of Chicago,[15] which operates on principles similar to those described by Drebin et al.[14] The process is as follows: the user defines an opacity transfer function, whereby the CT voxels are classified into the different tissue types. The opacity function allows the user to map tissues that are of no visual interest (eg, skin) to zero opacity, ie, transparency, and thus to visualize structures of interest which would otherwise be occluded. Once the tissues have been classified, rays are cast through the data, from the viewing point. As the rays traverse the data, they accumulate opacity weighted intensity, according to the mapping defined. When a ray has accumulated sufficient opacity, it terminates, and additional pixels have no further contribution. The weighted opacity accumulated by the ray determines the brightness of the rendered image pixel. The data can be rendered from any perspective desired by the user. It is also possible to eliminate parts of the data anteriorly and posteriorly, using a clipping or elimination plane. By advancing the near clipping plane, which is the one closest to the viewer, posteriorly into the data set, all data, which is anterior to the plane, is excluded from the rendering. This eliminates structures, which are superficial to organs of interest, which may be located deeper within the body (Fig 6). Thus, in some images presented in this work, the clipping plane was advanced into the data, so as to eliminate skin and fat and visualize lymph nodes with greater clarity.

The major advantage of the VR method is that with an appropriate choice of the opacity map the user can eliminate structures which are not of interest, and enhance structures which are important, without going through the time-consuming step of manual contouring or segmentation.

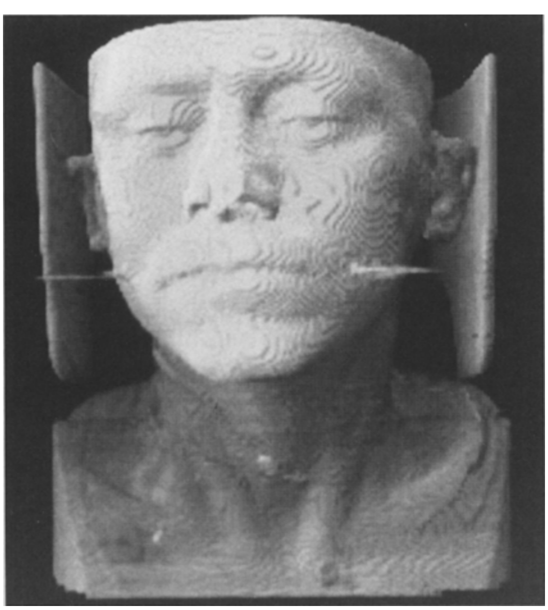


Fig 5. Volume Rendering in a normal patient showing the surface anatomy of the face, as well as the contour of the sternocleidomastoid muscle as if viewed by transparency.

RESULTS

Seven of 10 patients (four squamous cell carcinoma, one lymphoma, one Kikuchi's disease, one esthesioneuroblastoma) demonstrated enlarged lymph nodes. Disease was not detected clinically in four of them. The evaluation of lymph nodes was based according to the 1997 classification of the American Joint Committee on Cancer (AJCC) (Fig 7),[16] which was well evaluated in the coronal oblique view, using MPR, SSD, and VR. One of the patients demonstrated unilateral vein thrombosis by the MIP method, which was not as well appreciated in the pre-processing axial view. Except for MIP, the 3D imaging methods showed better the size and number of enlarged lymph nodes; the compression of airway by tumor; and the asymmetry, compression, and obstructions of airway by tumors. It can be stated that:

1. MPR is very fast and interactive, however the quality of image is limited by z-resolution of CT data set.
2. MIP was able to evaluate clearly stenosis, thrombosis, and displacement of the vessels. However, the visualization of the tumor, lymph nodes, and other anatomic structures was not possible by this method.
3. SSD combined with MPR showed more anatomic information than the isolated methods, avoiding the main disadvantage of SSD: preserve only the boundaries, contours and surface of a given anatomic structure.
4. VR is superior to the other techniques. It allowed us detailed visualization of the size and extension of the tumor, the lymph nodes and the relationship between vessels, bone, muscles, and other structures of interest (Fig 8). VR is hardware-intensive and limited by the necessity to standardize parameter sets for different tissues.

DISCUSSION

In the evaluation of head and neck tumors, in most cases, the radiologist defines the extent of the lesion, rather than establishes the diagnosis. The

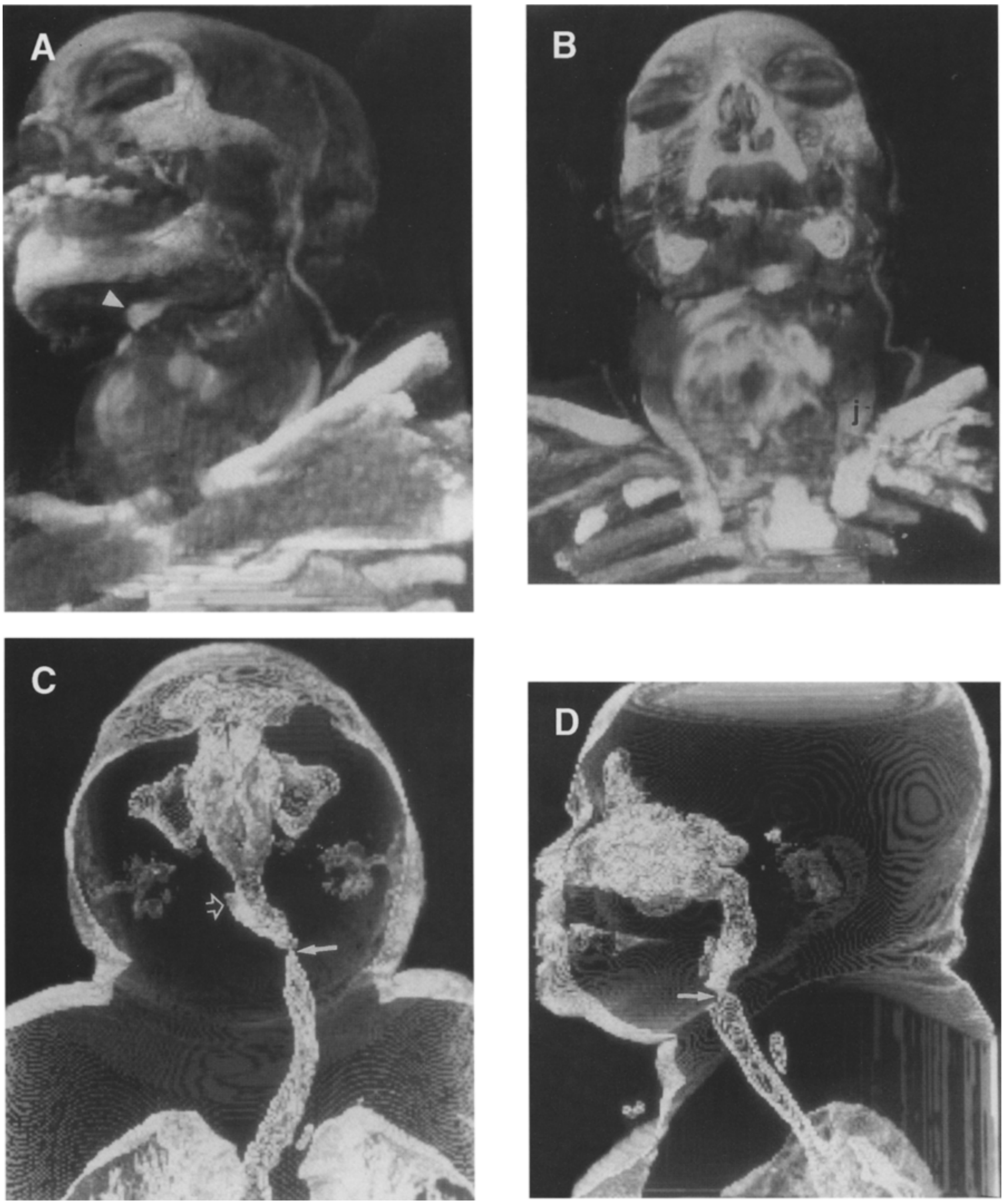


Fig 6. The same patient shown in Fig 1, biopsy-proven thyroid cancer. (A) VR, left coronal oblique view, shows the bulging cancer in the neck, and the opacity transfer function allows demonstration of the enlarged collateral veins. The hyoid bone is also visible (arrowhead). (B) VR image, coronal view reveals large thyroid mass extending from the level of the hyoid bone superiorly to the level of the clavicular head inferiorly. Note the lateral displacement of the vessel (j). (C and D) VR image, applied for airway, anteroposterior, and lateral views reveals anterior and left displacement of the airway, due to the tumor. The piriform sinus (open arrow) and true vocal cord (large arrow) are well seen. Skin-air and mucosal-air interface are well visualized.

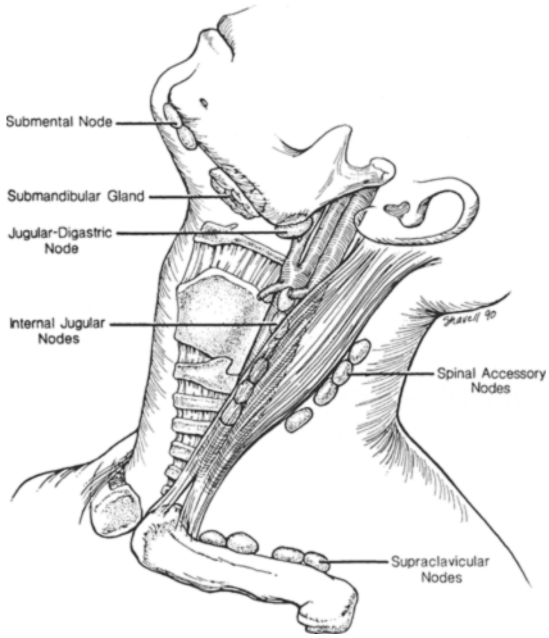


Fig 7. Anatomic illustration of normal lymph nodes chains. Reprinted with permission.[17]

clinical examination of the head and neck tumor along with radiographic evaluation forms the tumor, node, metastasis (TNM) staging system. However, clinical examination of patients with squamous cell carcinoma has an estimated false-negative rate ranging from 15% to more than 50%. CT is advantageous for evaluation is that it shows the presence and extent of nodal disease, and detects abnormal nodes beyond the range of physical examination, especially in the visualization of the deeper nodes (eg, the highest nodes of the superior internal jugular chain, and retropharyngeal lymph nodes). However, on a series of several dozen axial CT slices, it is hard to visualize the relationship between different anatomic structures. Although these images contain no more information than do the corresponding series of transverse scans, there is a consensus that the viewer can better appreciate spatial relationships in a 3D image than in a series of sections. 3D imaging methods have been developed for the purpose of permitting the radiologist and the referring physician to answer a number of important clinical questions beyond the diagnosis.

CONCLUSIONS

In our series of selected patients, the 3D imaging techniques used demonstrated the relationship between the lesions of interest and various anatomic structures. CT 3D volumetric analysis was found to be useful in the localization and staging of neck cancer, and thus can assist in surgical and radiation treatment planning. The images obtained in differ-

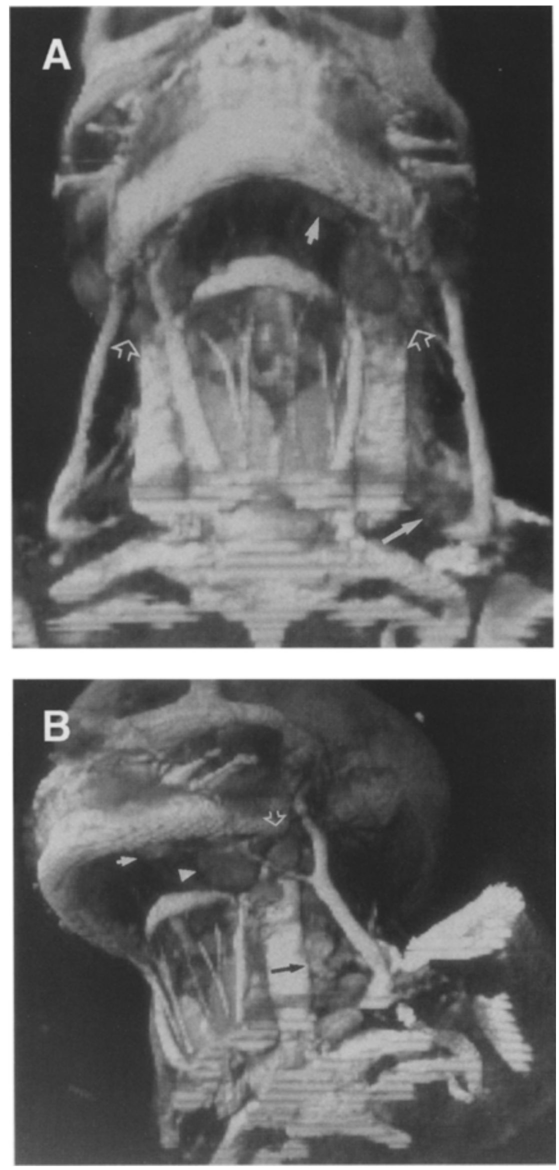


Fig 8. A 31-year-old woman with 1-week history of left neck fullness and tenderness. Biopsy shows Kikuchi's disease. (A) VR CT image, anteroposterior view, shows multiple diffuse adenopathy involving bilaterally the submental (small arrow), submandibular (open arrow) and supraclavicular (large arrow) chains. (B) VR CT image, left anterior oblique view, reveals multiple, large lymph nodes involving the submental (small arrow) and spinal accessory chains (large arrow), submandibular gland (arrowhead), and jugular-digastric node (open arrow) are well seen.

ent planes (eg, coronal, sagittal, oblique), provide new information beyond that already available on the axial slices. MIP proved useful only to study the patency of the vessels, excluding thrombus or compression by tumor. MIP was unable to visualize lymph nodes by levels or tumor extent, and thus could not be used for staging as an isolated technique. When compared with the current literature, this study also showed that VR has advantages over surface rendering, demonstrating the spatial relations between structures of interest that could not be obtained with the other methods, due to the preservation of image data, while surface rendering preserves only data that belongs to the surface displayed (Fig 2). In addition, VR has the ability to provide anatomic details and the spatial relations between structures of interest without prior manual segmentation, which means it is a time-saving technique for the user, facilitating your future application in the clinical setting. VR is hardware-intensive and limited by the necessity of to standardize parameter sets for different tissues. However, development of faster workstations and new software has allowed rapid evaluation and manipulation of the images. For example, the opacity transfer function can be preset or adjusted to render different tissues more or less visible.

In addition to the individual techniques, these various methods may also be combined to show more detail of the anatomy.

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